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DEVELOPMENT OF AN IMPROVED HARDBOARD-LUMBER PALLET DESIGN.(U)
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Research
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FPL 387
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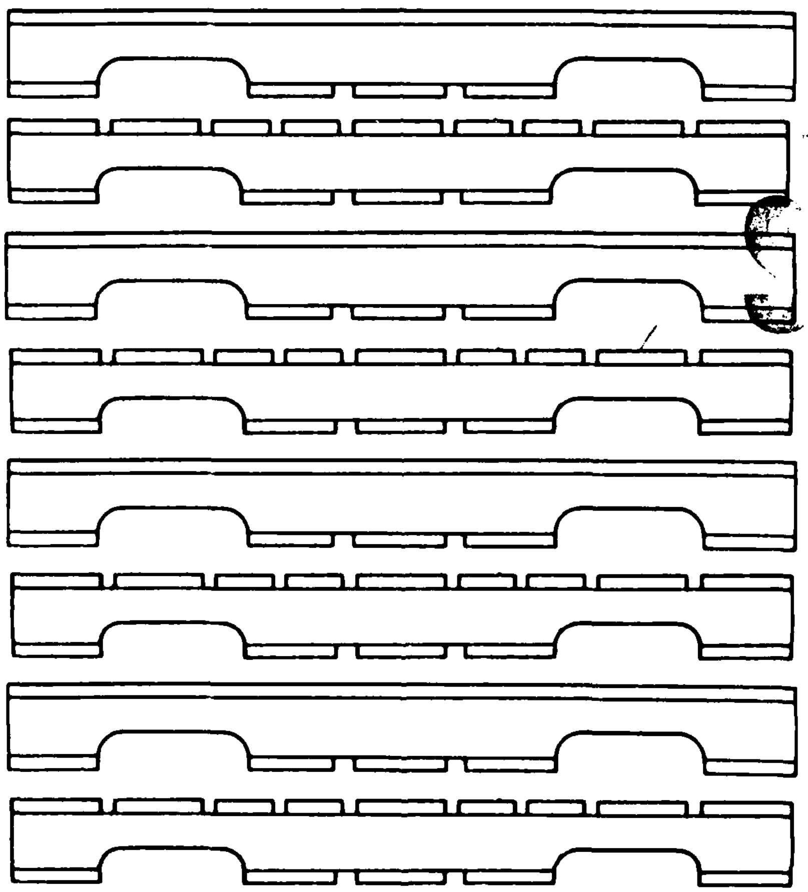
Development of An Improved Hardboard-Lumber Pallet Design



Abstract

Low-grade wood residue from logging and sawmilling operations could be used in the manufacture of hardboard for pallet construction, if shown to be satisfactory for this purpose. Generally, this evaluation compared the performance of notched stringer, partial 4-way entry oak pallets having 1-inch-thick medium-density hardboard decks with that of similar red oak pallets under laboratory and service-type conditions. The hardboard-lumber pallets withstood handling impact better; were more (or less) rigid in handling, depending on support conditions; racked much less because of cornerwise drop testing (but also failed sooner); and performed similarly, overall under indoor and outdoor handling and storage conditions. Preliminary work indicated that standard helically threaded pallet nails can be used satisfactorily for hardboard-lumber joints for both exterior and interior exposure. This information should be pertinent to pallet manufacturers and users of pallets, especially to those employing mechanized handling systems.

Acknowledgement

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Development of An Improved Hardboard-Lumber Pallet Design

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LETTER ON FILE

A

By
ROBERT K. STERN, Technologist

Introduction

Logging and sawmilling waste could be used for hardboard manufacture and subsequent pallet construction, if the resulting pallets were competitive with existing lumber counterparts. This would enhance the use of wood residues. To investigate this possibility Forest Products Laboratory (FPL) personnel have conducted research on different aspects of the problem. This report describes the results of the latest work toward evaluating the use of hardboard components[2] for the construction of returnable, exterior-type pallets. All comparisons involving full-size pallets in this work were based on the performance of notched stringer, partial four-way entry, flush type, nonreversible 48- by 40-inch pallets, because of their widespread use in shipping today.

Previously, Superfesky and Lewis had defined the basic engineering characteristics of three medium-density hardboards *(10)*.[3] Initial FPL work with the use of hardboard as pallet component material by Kurtenacker indicated that it might be used favorably for this purpose *(4)*. Later, Stern reaffirmed that the performance of block-type pallets with 1-inch-thick medium-density hardboard decks compared favorably with similar pallets having nominal 1-inch-thick red oak lumber top decks *(8)*. A separate study conducted at about the same time evaluated the performance of pallets of the same size (48 by 40 in.) as in *(8)*, but of the notched-stringer, partial four-way entry, reusable pallet style, and made with hardboard or insulation board decks of varied density with all other parts red oak. The performance of these were compared with that of all-lumber counterparts. This work *(9)* indicated that notched stringer pallets with 1-inch-thick hardboard top decks would probably yield similar performance as their red oak counterparts, except in resistance to diagonal impact distortion (produced by "free-fall" cornerwise drop testing). For this type of rough handling, the pallets with lumber decks racked on the order of 10 times more than the test pallets with hardboard decks, but they also held together for many more impacts.

One limitation in all of the previous FPL work involving use of hardboard as a pallet material was that urea formaldehyde resin was used as a binder. This was necessary because the panels were made for FPL by private companies according to their manufacturing procedure for commercial fiberboard. However, although fiberboard made with urea binder is adequate for indoor use and limited outdoor exposure, phenol-formaldehyde or phenol-resorcinol binders were considered necessary for general outdoor exposure because of their superior water resistance.

Materials

Hardboard

Previous research *(8,9)* indicated that medium-density hardboard of 1-inch thickness probably would be required to produce similar performance under all-weather service conditions, as nominal 1-inch red oak boards for some of the more important strength requirements in pallet construction. Because no sources of hardboard of this type were available

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] The term "hardboard" is used in this report to denote panel material made from wood fiber bound together with waterproof phenol formaldehyde adhesive.

[3] Italicized numbers in parentheses refer to literature cited at end of report.

at the time, it was decided to make panels 1 inch thick by bonding together two 1/2-inch sheets of hardboard. The composition of the chips used to make the hardboard was about 85 percent oak. The remaining 15 percent consisted of sweetgum, elm, and traces of other species. The wet-formed mats were made with 3 percent phenol-formaldehyde binder and 1 percent wax sizing under a contract with the North Little Rock (Ark.) Division of Superwood Corporation. Prior to expeditious shipment to FPL, the mats were prepressed to remove excess free water. Shortly after their delivery at the Laboratory, the wet-formed fiber mats were pressed again to a 1/2-inch thickness in a hot press heated to 375° F. Next, the mats were heat treated for 2 hours in an oven held at 300° F. Later, the mats were bonded together with phenol-resorcinol adhesive into panels 1 inch thick, allowed to set under pressure, and trimmed for use as pallet stock. The ovendry density of the panels was 38.6 pounds per cubic foot.

Lumber

Red oak pallet parts used in this work were cut from No. 3A and No. 3B common lumber obtained locally. From the time of arrival at FPL the lumber was stored underwater until machining just prior to pallet assembly.

Nails

The two types of nails used in this work were the following:

Description	Supplier	MIBANT value[a] range	average (degrees)
2-1/2-inch tempered, hardened, SSDP, helically threaded, diamond pointed. (Nailhead diameter—about 1/4 in.[b])	American Nail Co-op, Earth City, Mo.	16-21	18
2-1/2-inch "Grip-Tite roofing, galvanized. (Nailhead diameter—about 3/8 in.[b])	Wire Products Co., Hortonville, Wis.	44-58	52

[a] Based on tests of 25 nails of each type (note For greater detail on the MIBANT test apparatus and procedure refer to (6)
[b] The manufactured nailheads were not uniformly round for the approximate sizes given

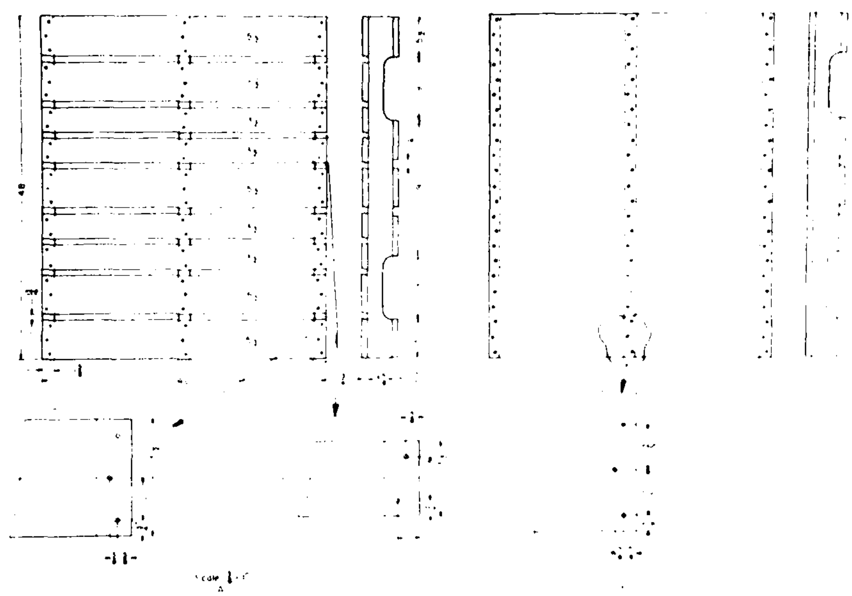

Figure 1.—Pallet designs evaluated in this work. (A) lumber control pallet with spaced top deckboards and (B) experimental pallet with hardboard top deck

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Preliminary Research

Objectives

The first goal of this portion of the work was to determine the details of a fair but accelerated laboratory exposure program for the hardboard-lumber pallets to represent exterior service conditions. Thus, screening of various arbitrary exposure conditions was necessary for determining the accelerated laboratory testing schedule to be used for the bulk of the testing included in this study.

A second objective concerned selection of a suitable nail design for joining the hardboard decks to lumber stringers. The results of this portion of the preliminary investigation would apply to both laboratory and field-type testing of loaded pallets conducted later. In previous FPL (accelerated) research involving loading, such as occurs in service, the heads of standard helically threaded pallet nails tended to pull through hardboard, instead of failing at the higher loads associated with axial withdrawal of the nails from the stringers *(8,9)*. Therefore, before constructing the test pallets, it was also considered necessary to estimate the influence of nailhead size upon the "pullthrough" tendency under axial loading for similar hardboard-lumber joints. The average area of the roofing nailheads, eventually selected for comparison with standard pallet nails in this work, was about 120 ± 10 percent greater than that of the pallet nails.

Results

This work indicated that accelerated cyclic exposure testing was excessive and that the outdoor ser-

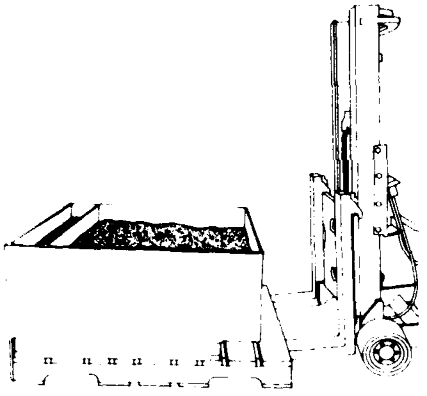

Figure 2.—Apparatus for handling impact testing.

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vice tests were necessary. Also, use of large head conventional roofing nails did not seem preferable over conventional helically threaded, hardened steel pallet nails. Details of the work supporting these conclusions are given in the Appendix.

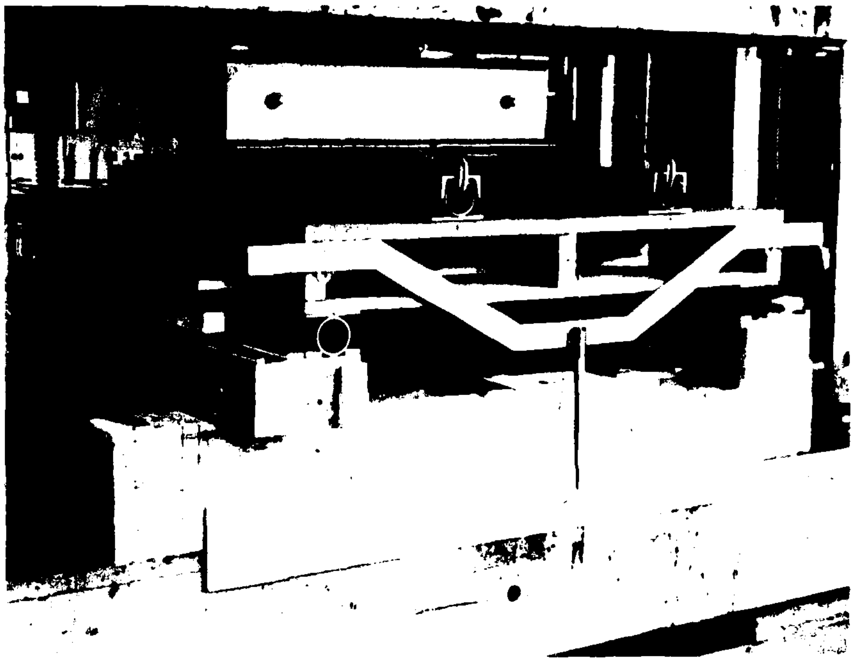

Figure 3.—Bending stiffness test of hardboard-lumber pallet with load being applied at the quarter points of the 36-inch span.

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Principal Experimental Evaluation

This part of the work involved tests of pallets in two phases begun at about the same time: (A) under accelerated laboratory testing conditions, and (B) involving handling and storage representative of service conditions. The laboratory tests included measurement of handling impact resistance, bending stiffness, and diagonal rigidity. Previously untested pallets were stressed repetitively to destruction for each type of test. Service-type handling and storage tests were conducted with loaded pallets on FPL property, in order to assure complete accountability and accessibility of the pallets for inspection during and after testing.

Specimen Preparation and Moisture Conditioning

The test specimens consisted of sixty 48- by 40-inch nonreversible flush-type notched stringer pallets. Top decks of one group of 30 pallets were made from the 1-inch-thick hardboard panels,[4] and the remaining portions were made from red oak lumber. The 30 comparative control pallets were similar, except that top decks consisted of nominal 1-inch, uniformly separated boards as shown in figure 1. The moisture content (MC) of the lumber at the time of pallet construction was above 30 percent—the fiber saturation point—in all instances during nailing. The fasteners used were standard helically threaded pallet nails of the type described earlier in this report. The newly constructed pallets were stored in a heated building at ambient atmospheric conditions for a minimum of 30 days prior to testing.

Laboratory Testing

Handling impact.—The primary reason for conducting tests of this type was to measure the resistance of typical pallets to this very common form of rough handling encountered in service. Specifically, the performance of five experimental hardboard-lumber pallets was compared to that of five all-lumber control pallets. Prior to each impact, the forks were tilted 4 degrees forward and positioned so that the upper sides contacted the pallet 8 inches from the right angles of the forks. Impact speeds of the forklift truck against the pallets averaged 2.0 miles per hour and ranged from 1.84 to 2.14. Testing of each pallet was repeated until it would have been unfit for further service unless repaired. Testing of hardboard-lumber pallets was halted if "forkbite" (i.e., indentation of the leading edge of the hardboard top deck) progressed to a depth of 2 inches or more. All of the tests were conducted with a conventionally equipped forklift truck, i.e., without attachments such as the FPL "impact panel" *(7)*. A sketch of the test configuration is shown in figure 2.

Bending stiffness.—Tests of pallet rigidity were considered to be necessary because of the danger, cost, and inconvenience caused by failure on this account. Pallet bending stiffness becomes most important when the loaded pallet is (a) being transported by forklift truck (especially over rough terrain), or (b) is stored in a rack without support, except near its ends—as happens in "drive-in" or "drive-in, drive-through" racks. Therefore, as is specified by ASTM D1185-73 *(2)*, each of the

[4] A detailed description of the hardboard and lumber composition and processing are given earlier in this report.

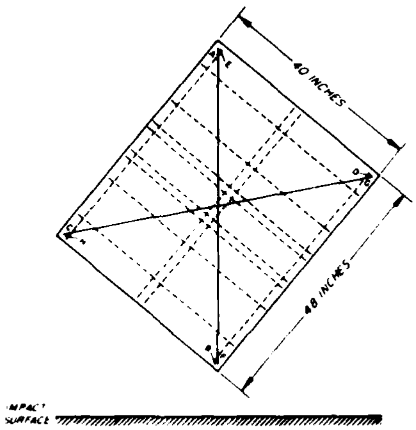

Figure 4.—Pallet orientation showing diagonals during diagonal rigidity test.

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pallets was loaded from zero to failure in bending at the quarter points of the 36- and 44-inch spans as shown in figure 3. The loading was applied at 0.2 inch per minute by a universal testing machine, and deflection at the midpoints of each span was sensed by the movable elements of two linear variable differential transformers (LVDT). The LVDT's were mounted on metal yokes suspended from the ends of the two outer stringers, and the resulting voltages were fed into an x-y recorder. Thus, sets of 5 pallets per group and four groups made a total of 20 pallets tested.

Diagonal rigidity.—Racking of pallets out of rectangular shape during use can produce costly time delays—especially if they are being used with an automatic palletizer of a continuous conveyor or in computer-controlled automated systems. Obviously, it would also be costly to repair or replace them, if they became damaged excessively. Therefore, these tests of 10 pallets (i.e., 5 each of experimental hardboard-lumber construction, and a second group of all-lumber pallets) were conducted as a part of the general evaluation of hardboard for pallet construction. The objective of these tests was to compare the diagonal rigidity of hardboard-lumber pallets with that of the oak pallet controls by cornerwise, free-fall drop testing.

Each pallet was dropped from 40 ± 1/8 inches above a 2-inch-thick steel plate embedded in the concrete floor supported by bedrock. Prior to release, the pallet was suspended from such a position on the corner so that the diagonal across the top deck of the pallet was perpendicular to the dropping surface. Individual pallets were dropped 12 times or until the pallet damage reached a point that it would have been unserviceable unless repaired. Racking of each pallet was monitored by changes in the original length of diagonals measured approximately 1.4 inches in from either corner. Changes in the length of pairs of diagonals on the adjacent top and bottom sides of the pallets, as indicated in figure 4, were averaged for each drop and used as a measure of pallet rigidity. The test procedure and data report complied with that specified in ASTM D1185-73 (2).

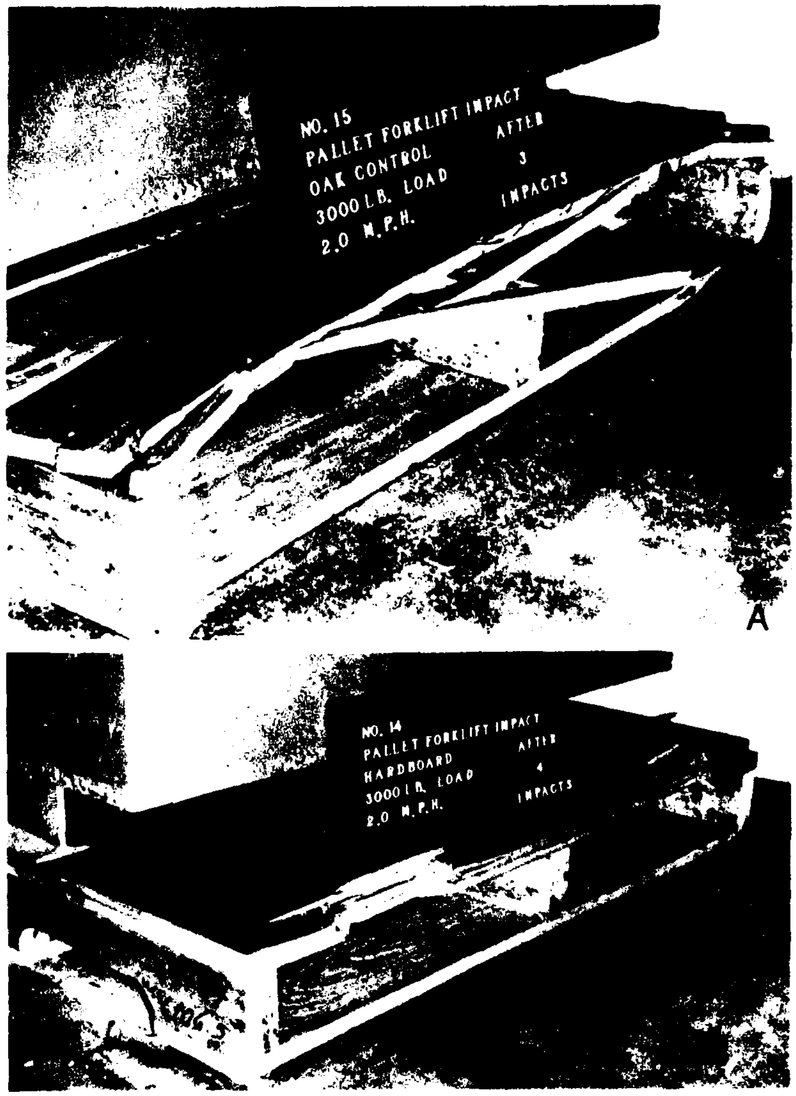

Figure 5.—Representative condition of pallets after failure from handling impact testing: (A) Lumber control and (B) hardboard-lumber pallet.

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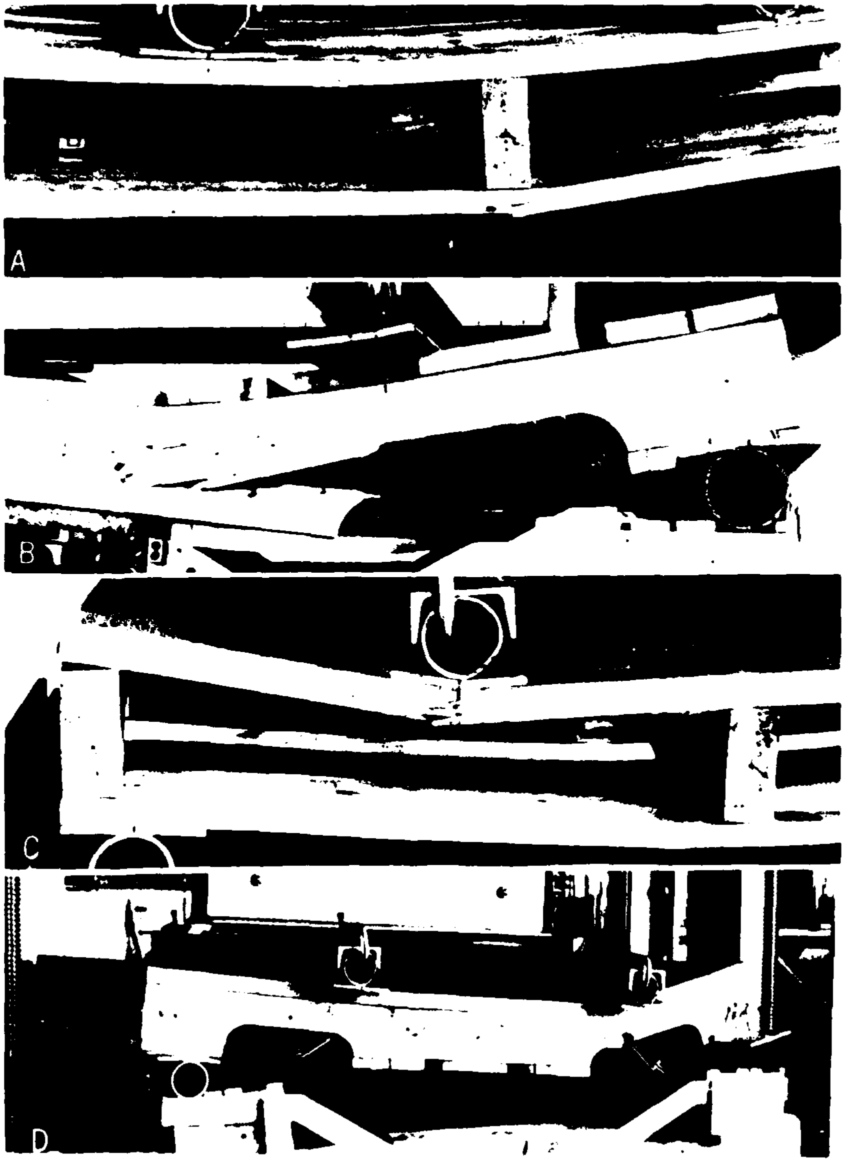

Figure 6.—Pallet failure patterns resulting from bending stiffness testing controls loaded (A) across 36- and (B) along 44-inch spans. Also, hardboard-lumber pallets loaded (C) across 36- and (D) along 44-inch spans.

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Discussion of Results

Handling Impact Tests

Lumber control pallets.—As testing progressed, the damage patterns observed were quite similar to those encountered in *(9)*. Specifically, all of the lumber control pallets failed by a combination of splitting and nailhead pullthrough of the top leadboard. Usually, splits were associated with unrelieved stress caused by the nails. The total number of impacts required for pallet failure ranged from two to four and averaged about three. Typical condition of a lumber control pallet after testing is shown in figure 5A.

Lumber pallets with hardboard decks.—As expected, failure occurred in lumber pallets with hardboard decks in every instance because of "forkbite"—i.e., indentation at the contact points between the forklift truck and the leading edge of the hardboard deck. When progressive forkbite reached a cumulative total of 2 inches in depth, further testing of that particular pallet was halted (fig. 5B).

All of the nail joints remained intact in this test series.[5] As shown by table 1, lumber pallets with hardboard decks withstood 2 to 13 impacts and averaged about 6. Thus, for this type of service-simulated testing the experimental hardboard-lumber pallets were better than their all-lumber counterparts.

Bending-stiffness tests.—Typical failure patterns obtained are illustrated in figure 6. The all-lumber controls in figures 6A and 6B represent quarter-point loading across the 36- and 44-inch span lengths, respectively. Excessive bending stress was the cause of failure of the bottom leadboard at its center, and the stringers failed mainly because of tension perpendicular to the grain along with excessive shear stress at the neutral axis. Figure 6C represents hardboard deck failure at the quarter point in the 36-inch span, while figure 6D illustrates failure caused by tension and shear stress failure beginning at the notches. The left arrow indicates how a typical split has begun to open at the upper right portion of the left notch. Similarly, the presence

[illegible]

Table 1.—Handling impact test results of loaded pallets

Pallet composition	Pallet description	Handling impact data: Individual pallets	Range	Nominal average
		Impacts		
Lumber (controls)	[1]	4, 2, 3, 2, 3	2-4	3
Lumber with hardboard decks	[1]	2, 4, 6, 4, 13	2-13	6

[1] See "Materials" and "Specimen Preparation and Moisture Conditioning" of "Principal Experimental Evaluation."

Table 2.—Data summary for bending stiffness test results

Pallet composition	Unsupported span	Maximum load: Range	Maximum load: Average	Pallet stiffness: Range	Pallet stiffness: Average	Index for hardboard pallets/controls
	In.	Lb	Lb	Lb/in.	Lb/in.	
Lumber (controls)	[1]36	11,750-13,620	12,750	7,184- 8,547	7,983	0.753
Lumber with hardboard decks	[1]36	5,950- 7,500	6,365	5,576- 6,608	6,040	
Lumber (controls)	[2]44	2,875- 4,700	3,990	10,101-10,989	10,480	1.380
Lumber with hardboard decks	[2]44	3,350- 9,400	6,420	11,976-17,143	14,465	

[1] Loaded across stringers
[2] Loaded along stringers

Table 3.—Distortion resulting from diagonal rigidity testing

Pallet composition	Number of cornerwise drops: Individual pallets	Group average	Average pallet distortion: Δ diagonals A-B,E-F		Δ diagonals C-D,G-H	
			In.	Pct	In.	Pct
Lumber (controls)	12, 12, 12, 12, 12	12	-1.36	-2.29	+ 1.30	+ 2.19
Hardboard deck, lumber parts otherwise	6, 3, 2, 2, 2 (to failure)	3 (to failure)	-0.34	-0.57	+ 0.11	+ 0.18

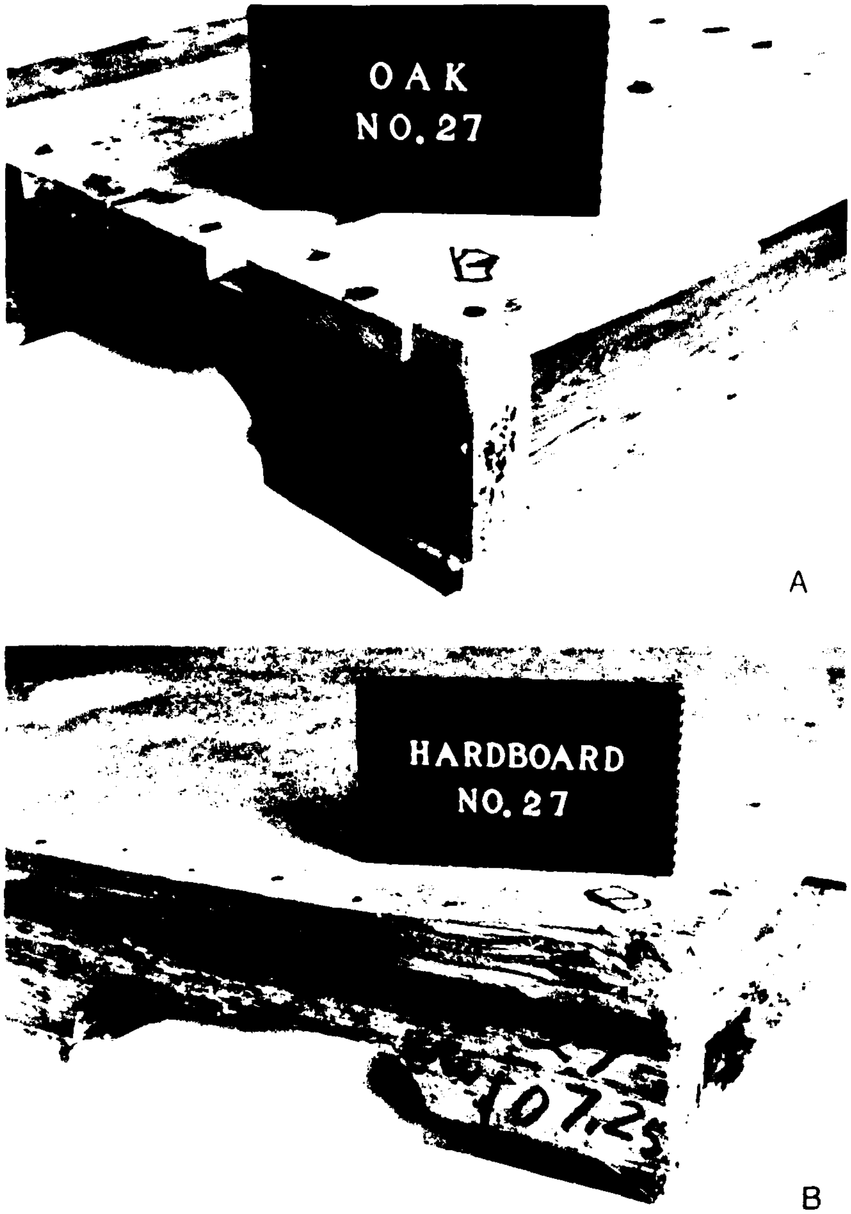

Figure 7. —Typical pallet condition after diagonal rigidity testing. (A) lumber control and (B) hardboard-lumber pallet.

of a knot and associated grain distortion indicated by the arrow near the upper portion of the notch on the right has diverted grain separation temporarily, but then large-scale grain separation (horizontally in the stringer) and pallet failure ensued.

The quantitative magnitude of the load and stiffness values involved are shown in table 2. In comparing the performance of the two types of pallets, it is obvious that the top deckboards of the lumber controls were functional when the pallets were loaded as 36-inch spans—i.e., across the stringers. This produced an average stiffness of 7,983 pounds per inch, i.e., about 32 percent higher than the comparable value for the hardboard-lumber pallets. However, the average stiffness of hardboard-lumber pallets was about 28 percent higher than the lumber control pallets when the 44-inch span was involved. The cause of this reversal can be readily understood when one considers the two types of pallet construction. For the 36-inch span, the composite stiffness of the boards exceeded that of the hardboard deck. However, because the boards of the lumber pallet decks were separated, they did not function when loaded along the 44-inch span, but the hardboard panel did. This inherent difference between the two versions of pallet construction might favor use of all-lumber pallets, if they are to be moved over rough terrain. Hardboard-lumber pallets would, however, have an advantage if they are moved over normal pavement and are stored temporarily in racks without bridging between the front and rear rails.

Diagonal rigidity tests.—As could be expected, damage and failure patterns for this type of testing repeated that experienced during earlier work involving notched-stringer lumber pallets and experimental pallets made with hardboard decks and lumber parts *(9)*. Without exception, the lumber control pallets withstood the prescribed maximum of 12 drops from 40 inches, but they also racked severely. In contrast, the lumber pallets with hardboard decks tended *to fail after an average of three drops* but they also racked much less up to that stage. The magnitude of the comparisons is shown in table 3. The relatively good condition of the lumber leadboards after the required 12 impacts is indicated by figure 7A. However, the same illustration also shows the moderately racked condition of the lumber and "nailhead pull-through" that resulted from the 12-drop series. The comparable condition of a hardboard-lumber pallet after three impacts is shown in figure 7B. As indicated, the top deck crushed much more (on one-fourth as many impacts), but also racked much less than the lumber pallets. This failure mechanism often included shear failure at the notch, as shown in figure 7B.

Service-Type Handling and Storage

Testing

While the laboratory testing schedule was an accelerated evaluation procedure based on logical tests of the pallets' most important strength characteristics, a fair comparison of the performance of hardboard-lumber pallets required that actual service environmental exposure be conducted at about the same time with a group of similar pallets. Therefore, to ensure 100 percent accountability of the pallets used—a factor essential to data analysis—the pallets were tested on FPL property only. Specifically, 20 pallets (10 lumber controls and 10 experimental hardboard-lumber pallets) were each loaded with a tare weight of 1,800 pounds, consisting of two steel 55-gallon drums filled with sand, and given the following storage and handling exposure:

Started	Completed	Length of exposure Days	Shuttling Cycles
	First Outdoor Storage and Handling		
12-04-78	12-27-78	23*	3*
	Indoor Storage		
12-27-78	1-17-79	21	4*
	Second Outdoor Storage and Handling		
1-17-79	2-07-79	21	6
	Additional Outdoor Storage		
2-07-79	8-17-79	190	—

*Some variation in the length of exposure and amount of handling occurred unavoidably because of inclement weather and necessary forklift truck servicing during the testing.

Figure 8.—The FPL forklift truck in operation handling a loaded experimental hardboard-lumber pallet.
(M 147 215-8)

The condition of the pallets was monitored periodically, except on weekends, during the regularly scheduled 9 weeks of the program and after the additional 190-day static outdoor storage period that followed. Handling and shuttling were done in all instances with the Laboratory's 6,000-pound capacity LP gas operated forklift truck shown in figure 8. The speed employed for handling was about 0.2 mile per hour and 0 to 10 miles per hour for shuttling and transfer.

First outdoor storage and handling.—The 20 loaded pallets were stored outdoors for 23 days and shuttled a total of three times during this period. The first half of a single shuttling cycle consisted of moving the loaded pallet about 600 feet by forklift, leveling the loaded pallet, placing it on the pavement, and then withdrawing the forks. The second portion of the cycle involved reversal of the procedure. During transfer, the mast, forks, and loaded pallets were always tilted 4 degrees toward the rear of the forklift. Also, during lateral transfer the forklift and its load received vertical jolts of varied magnitude as the truck ran over cracks, expansion joints in the concrete, and other irregularities.

At this time it was decided that the arbitrarily adopted handling conditions were excessively severe and nonrepresentative of service handling. Accordingly, the dummy loads and supports were repositioned on the pallets to allow subsequent handling from the opposite, previously undamaged ends and subsequent shuttling for each trip was reduced to a distance of 100 feet.

Indoor storage.—Following the first 23 days of outdoor storage with interim shuttling, the modified, loaded pallets were moved to an indoor storage area. For this stage in the overall program the 20 loaded pallets were divided into two equivalent groups and stored in racks, or directly on the concrete floor nearby. The loaded pallets, in storage, in the racks were supported only by their ends. (Note: this is also typical in service in "drive-in" or "drive-in, drive through" rack storage systems.) During indoor storage the loaded pallets were handled and shuttled four times along the concrete floor for a distance comparable to that used during the first and last parts of this portion of the work.

Followup outdoor storage.—As a third step, the loaded pallets were then transferred to the original storage location and given similar treatment to that described for the "first outdoor storage and handling" period, except that the loaded pallets were stored for 21 days and handled and shuttled six times to a distance of about 100 feet.

Following this last scheduled storage and handling period the loaded pallets were left in static outdoor storage for an additional 190 days. They were then examined and further testing was ended.

Results

The thickness of hardboard decks of hardboard-lumber pallets swelled a maximum of about 2 percent during the entire exposure. Much of this occurred during the first 2 weeks. Also, there was no problem evident from nailhead pullthrough.

Another observation concerned the serviceability of hardboard-lumber pallets when compared with their all-lumber counterparts after months of exposure and handling. In general, the two groups of pallets performed similarly, but there were differences. A brief summary of deleterious effects of service on both types of pallets in the rack storage portion of the indoor tests is given in the following:

Although this comparative study was ended after a total of 8-1/2 months—practically all of which involved outdoor exposure, roughly equivalent pallet resistance to handling and atmospheric exposure was observed for both types of pallets. The fact that the hardboard panels did not soften markedly with extended exposure to moisture probably was linked directly to the high water resistance of the phenol-formaldehyde binder.

As might be expected, damage such as is shown in figure 10C did not occur in any of the loaded pallets that were stored directly on the floor during indoor testing. The major difference between this type storage and storage in racks was that the middle portion of the bottoms of the loaded pallets was supported in floor storage, but not in rack mounting.

It became quite clear as the work progressed that the transfer of loaded pallets between buildings, i.e., long-distance shuttling, produced much of the damage to loaded pallet ends. This probably was associated with tilting of the forks, and pavement irregularities.

In general, allowable cross-grain *(5)* in stringers and deckboards did not affect the results. Similarly, the average unloaded pallet weights of 65.6 and 83.2 pounds for all-oak and hardboard-oak pallets, respectively (a difference of about 27 pct), did not appreciably affect the results of this work.

	Phase	Principal Changes
I.	Initial 23-day outdoor storage and handling period.	Shear failures of the top deck leading edge of some of the lumber controls and tension failures in the hardboard-lumber pallets (fig. 9). Also, checks and splits tended to enlarge in all lumber components.
II.	Indoor storage and handling for 21 days.	Leading edges of some leadboards tended to lift and split (figs. 10A, 10B). A product of this storage mode: split, beginning at the notch, caused by bending stress of pallet in storage (fig. 10C).
III.	Second outdoor storage and handling for 21 days.	A minimal progression of damage described under Phase I.
IV.	Storage for an additional 190 days.	Practically no change in the density of pallet components or in damage produced prior to the beginning of this period.

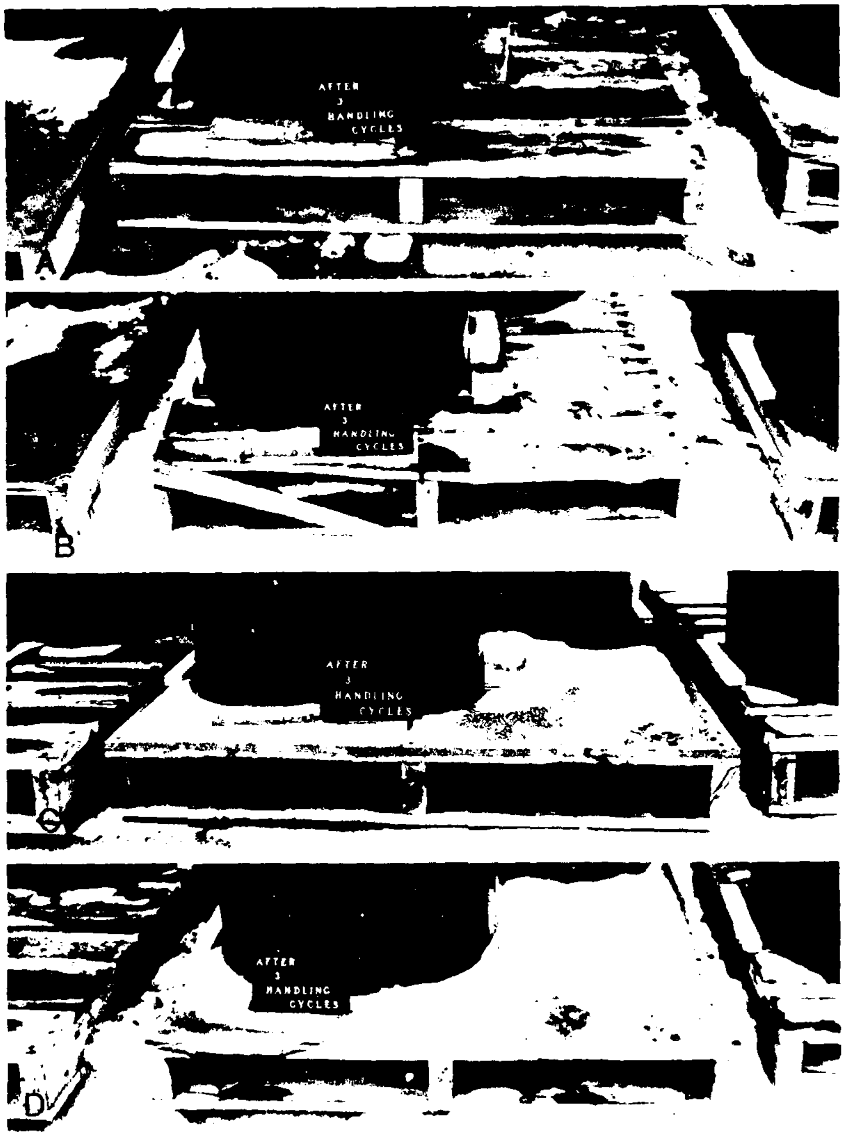

Figure 9.—Contrasting conditions of pallets during the initial 23-day storage and handling exposure: (A) lumber pallet (control) in good condition, (B) damage from vertical shear, (C) relatively unaffected hardboard deck, and (D) vertical shear effect upon its counterpart.

(M 147 216 6)

Figure 10.—Damage to pallets being stored in a rack during indoor storage. (A) a general view, (B) split endboard (probably caused by transfer over an irregular pavement), and (C) tension perpendicular to the grain failure in stringer during rack storage.

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M 147 241-8
M 147 241-9

Conclusions

Based on this and the referenced work in *(8,9)*, the following conclusions can be made about the use of hardboard of the type evaluated for standard pallet construction:

1. In many types of comparative evaluations, hardboard-oak pallets of the size and type evaluated will perform about as well or better than red oak returnable pallets of similar size and style—especially when used with mechanical handling systems.
2. This use represents a good outlet for limbs and sawmill waste, such as short lengths and miscut or twisted lumber. As the price of all-lumber pallets continues to increase the use of hardboard construction becomes more attractive economically.
3. Hardboard-oak pallets of this size and style rack less, but fail sooner, than similar red oak lumber pallets under cornerwise impact testing. Therefore, they might be more suitable for automatic pallet handling operation, but less suitable if considerable cornerwise dropping is expected.
4. Use of phenol-formaldehyde binder in hardboard panel manufacture can achieve similar all-weather performance capability as red oak deckboards of pallets of the same size and style, but this practice might also increase pallet cost above that for lumber pallets.
5. Nailhead pullthrough probably will not be a serious problem in the use of medium-density hardboard for pallet construction if phenol-formaldehyde is used as a binder.

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APPENDIX— PRELIMINARY RESEARCH DETAILS

Testing

Exposure followed by tensile testing of joints.—Ten nail joints were constructed by nailing together single 4- by 2- by 1-5/8-inch pieces of hardboard to 6- by 3- by 1-5/8-inch pieces of red oak. A single standard 2-1/2 inch, helically threaded, hardened steel pallet nail was used to fasten each piece of hardboard and lumber together to make the simulated joint. A similar set of 10 specimens was also made entirely from red oak lumber, except that 3/4-inch (nominal 1 in.) red oak was used instead of 1-inch hardboard.

Following construction, the two sets were each given one exposure cycle of the six specified in the "Accelerated Aging Cycle" of *(1)*. Specifically, this involved the following steps in the order shown:

1. Immersion in water at 120° ± 3° F for 1 hour.
2. Spraying with steam and water vapor at 200° ± 5° F for 3 hours.
3. Storage at 10° ± 5° F for 20 hours.
4. Heating at 210° ± 3° F in dry air for 3 hours.
5. Spraying again with steam and water vapor at 200° ± 5° F for 3 hours.
6. Heating in dry air at 210° ± 3° F for 18 hours.

Following accelerated aging exposure, the simulated pallet joints were conditioned for at least 48 hours in an atmosphere of 68° ± 6° F and a relative humidity (RH) of 65 ± 1 percent. At this time the two sets of specimens were given axial tension tests at a loading rate of 17.5 inches per second. The testing equipment consisted of a servo-controlled electrohydraulic testing system. The deflection transducer output was digitized by a high speed digital storage oscilloscope and transferred subsequently to an x-y plotter.

Results of aging and subsequent tensile tests.—As accelerated aging testing progressed, a large degree of swelling occurred in the hardboard. This swelling suggested that use of a milder exposure schedule might be more realistic and advisable to prevent premature joint failure. This suspicion was reinforced when (untypically) 7 of 10 all-lumber specimens failed during the tensile test by nailhead pullthrough.

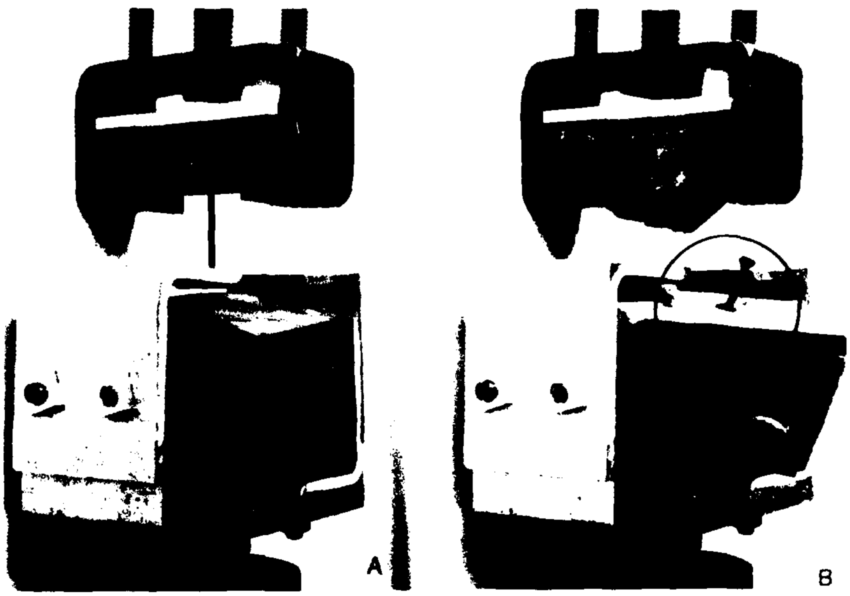

Figure 11.—Two failure mechanisms produced by nail withdrawal testing: (A) nail withdrawal and (B) nailhead "pullthrough."

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Figure 11 shows the two failure mechanisms resulting from these tests. Part A illustrates the result of a conventional nail withdrawal sequence wherein the nailhead essentially remained in its original position and the shank pulled away from the stringer section. In contrast, nailhead pullthrough obtained with the same type of joint is illustrated in Part B. For this pattern the withdrawal force probably reached a maximum when the fiber directly below the nailhead (encircled) failed during the initial stage of failure. As the nailhead was pulled through the hardboard, the lower portion pulled free and then failed in bending.

Quantitatively, an average maximum force of 514 pounds was required for the hardboard-lumber joints and 577 pounds for the all-lumber joints failure by nailhead pullthrough. The remaining three all-lumber joints required an average maximum force of 683 pounds, and the average for the entire set of 10 all-lumber joints was 618 pounds. The results obtained from this set and other combinations tried during this preliminary testing phase are given in table 4.

In view of the foregoing performance and because all-lumber pallets seldom fail in use by nailhead pullthrough, it was decided to continue searching for a more practical preliminary exposure procedure.

Twenty-four-hour soaking followed by tensile testing.—In the second portion of the preliminary research, 20 nail joints were given nail withdrawal tests immediately after a 24-hour soaking in water. This rigorous environment was selected because of the likelihood that the true significance of the use of hardboard in construction of outdoor-type pallets ultimately rests with its resistance to moisture. The principal differences between this and the first set of tests were that (a) a 24-hour water immersion replaced the one cycle of the D1037 accelerated-aging program, (b) the large head galvanized roofing nails described earlier were included, and (c) the replication was reduced from 10 to 5 in the four groups tested. A listing of the principal combinations of variables, as well as the results obtained for this series, are given in table 4.

Table 4.—Tensile test details for simulated deckboard stringer joints following accelerated aging

Test specimens[1]		Nail joints/group	Type of failure		Maximum force[2]	
Composition	Nail type		Nailhead pullthrough	Shank withdrawal	Range	Average
					---- Lb ----	
		AFTER 1 ASTM D1037 CYCLE *(1)*				
All oak	Helically threaded	10	7	3	500-770	618
Hardboard-oak	Helically threaded	10	10	0	400-695	514
		AFTER 24-HOUR WATER IMMERSION				
All oak	Helically threaded	5	0	5	295-672	478
All oak	Roofing	5	0	5	495-925	647
Hardboard-oak	Helically threaded	5	0	5	435-507	461
Hardboard-oak	Roofing	5	0	5	434-597	509
		NONE				
All oak	Helically threaded	5	0	5	452-667	576
All oak	Roofing	5	0	5	405-775	585
Hardboard-oak	Helically threaded	5	3	2	443-621	486
Hardboard-oak	Roofing	5	0	5	394-585	490

[1] Each held by a single nail joint.
[2] Based on the approximate maximum force exerted by individual nails during the tension tests.

As indicated, all joints in this series failed by withdrawal of the shanks from the oak stringer sections, and the averages of the peak withdrawal loads for each kind of nail were similar. The one exception involved joints of oak deckboards and stringer sections nailed together with large head roofing nails. Quantitatively, the average withdrawal force for this combination was 647 pounds and ranged from 495 to 925 pounds. In contrast, the mean peak withdrawal forces for hardboard-oak joints were 461 and 509 for the conventional pallet nails and roofing nails, respectively. The maximum withdrawal forces for the conventional helically threaded pallet nails ranged from 435 to 507 pounds, while the corresponding range for roofing nails was 434 to 597 pounds. However, it appeared to be inadvisable to use large head roofing nails instead of standard helically threaded pallet nails because of the sharp loss of initial withdrawal resistance likely in service. This phenomenon is clearly shown by Kurtenacker in *(3)*, figure 7.

Nail joints of green members without aging.—This, the last portion of the preliminary testing, was conducted without accelerated aging.

Results of tests of green member joints.—Considered collectively, the maximum tensile load sustained by the all-oak controls averaged about 19 percent higher than comparable sets of hardboard-lumber joints. However, the average for the maximum force required to fail hardboard-lumber joints was similar, whether or not the joints were previously immersed for 24 hours prior to tensile withdrawal testing.

The failure patterns, averages, and ranges of tensile withdrawal force sustained by each combination are given in table 4.

U.S. Forest Products Laboratory.
Development of an Improved Hardboard-Lumber Pallet Design, by R.K. Stern. Madison Wis., FPL 1980.
12 p. (USDA For. Serv. Res. Pap. FPL 387).

Low-grade wood residue from logging and sawmilling could be used for manufacture of hardboard for pallet construction, if shown to be satisfactory for this purpose.

Performance of notched stringer, partial 4-way entry oak pallets with 1-inch-thick medium-density hardboard decks is compared with that of similar red oak pallets under laboratory and service-type conditions in this evaluation.

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